TURBULENCE MEASUREMENT IN THE BENTHIC BOUNDARY LAYER FOLLOWING A STORM: INFLUENCE ON SEDIMENT RESUSPENSION AND RATE OF DEPOSITION

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Award #: N00014–96–1–5023

LONG–TERM GOALS

The principal objective of this work is to contribute to the development of effective remote autonomous mine countermeasure operations by providing pertinent flow, heat flux and sediment transport characteristics in the benthic boundary layer to missions engaged in sea mine reconnaissance and hunting. These environmental characteristics govern acoustic and light propagation, chemical and biogenic activity in the bottom boundary layer, distribution of sediment over a buried mine and other physical processes, knowledge of which is critical to the effective performance of acoustical, chemical or other sensory–based methods for mine detection and MCM operations.

OBJECTIVES

The specific objectives of the proposed project are to make velocity, temperature, salinity and suspended–sediment concentration measurements in the benthic turbulent boundary layer on the continental shelf off the coast of Florida and to develop models which meaningfully relate the measurements to the sea state, to the distribution and mobility of surficial sediments and to the heat flux characteristics of the boundary layer. The AUV deployable turbulence–measurement platform developed at Florida Atlantic University under ONR sponsorship will be established as a reliable low–noise AUV platform through resolution of any outstanding noise issues. Velocity and temperature gradients, Reynolds stress and kinetic energy distributions and dissipation rates in the benthic boundary layer will be determined and the influence of natural and suspended–sediment induced stratification will be examined; these measurements are of direct dynamical significance to the activity in the boundary layer. Near–bed measurements are best carried out in a controllable laboratory environment and pertinent laboratory experiments will be conducted to obtain parameterized information which will be related to measured quantities in the field. The aim will be to examine the role played by surface waves and currents in the distribution of bed stress, the molding of bed micromorphology and the rate of scour and deposition of sediments. The influence of significant sea states on a stratified bottom boundary layer and estimates of the contribution to the measured kinetic energy which can be attributed to the wave motion will be considered numerically.

C. Approach

A program for making turbulence measurements in the benthic boundary layer, using the AUV–deployable turbulence platform developed at Florida Atlantic University, under different, simultaneously measured sea states, is proposed. The measurements will be supported by laboratory experiments to determine very near bed effects and numerical modeling to examine the coherence between the measured total velocity in the bottom boundary layer and the independent, simultaneous wave measurement.

Field Turbulence Measurement.

Two main problems that have to be addressed in making measurements using the turbulence platform developed at Florida Atlantic University for deployment with FAU's autonomous underwater vehicle, *The*

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **Turbulence Measurement in the Benthic Boundary Layer Following a Storm: Influence on Sediment Resuspension and Rate of Deposition**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Atlantic University,Department of Ocean Engineering,777 Glades Road,Boca Raton,FL,33431**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Ocean Explorer are (i) vehicle noise and (ii) adequacy of sensors used. The first problem is being addressed currently and measures are being taken to isolate and, where possible, eliminate noise associated with stern plane controls and the propeller of the vehicle. Further, the significance of the measured noise to turbulence measurements is being assessed. Checks on the reliability of the current measurement system will be provided as described below. Regarding the second issue, the sensors being utilized will allow measurement of velocity and temperature corresponding to the dissipation range of the turbulent energy spectrum as well as measurement of concentration of suspended sediments. The measurements can be related to the bed stress using the method described by Dewey and Crawford [1] and to sediment transport using models described by Smith and McLean[2], with improvements proposed in section 4.3 below.

<u>Regional, sea–floor and temporal conditions</u>. Bottom boundary layer surveys in two areas over the continental shelf off the coast of Florida at depths of 20 to 40m are planned as the main part of the proposed study. First, an area 5 – 8km off the east coast, near Boca Raton, will be surveyed. This is influenced by the Gulf Stream and is constantly subjected to strong currents. Second, an area off the west coast, near Tampa, will be considered. This area is protected and is relatively quiescent. In both cases, where possible the choice of a particular location will be coordinated with other concurrent efforts, including one involving acoustic sediment–classification techniques, so that sidescan sonar information on bottom topography is available. Independent information on bottom micromorphology will also be obtained by divers using underwater video and through examination of soil samples. Measurements will be made in summer and winter. In summer, the east coast is frequented by storms and it is aimed to make measurements following a storm.

<u>Turbulence measurement platform</u>. The turbulence measurement platform developed at Florida Atlantic University (figure 1) consists of two high–wavenumber airfoil (shear) velocity probes, a dynamic Pitot tube, a fast response FP–07 thermistor (from Thermometrics), two cross–stream accelerometers and an electromagnetic current meter (from Marsh McBirney), mounted on the nose of the AUV. The microstructure thermistor will be mounted closer to the location of the shear probes than shown in figure 2b so that heat flux in the bottom boundary layer can be estimated. The AUV also has a newly installed RDI Acoustic Doppler Current Profiler (ADCP, also referred to as DVL) which has the bottom–tracking capability as well as the ability to measure velocity in the water column with an accuracy of 0.2% of measured velocity ± 0.2cm./s, through time–gate measurement of acoustic Doppler shifts. Both speed and direction information is obtained by the ADCP; its minimum and maximum range of measurement is 1m and 50m respectively using a 600kHz signal. A CTD package on board the AUV measures the conductivity and salinity while information about the attitude of the vehicle is supplied by a Watson Block self–motion package. Signals from the ADCP, the CTD package and the Watson Block will be monitored in conjunction with those from the turbulence package for use in data processing.

<u>Turbulence Measurement Program</u>. The EM current meter measures the vehicle speed relative to the water in the vicinity of the shear probes. The ADCP measures the vehicle speed relative to the seabed. Thus the local current velocity can be obtained as a difference between the two measurements. The ADCP also provides the mean velocity profile of the water column beneath it, to within, typically, 1m of the AUV and mean velocity shear can be determined directly from this data. Semi–independent checks of this measurement will be provided using the EM current meter in conjunction with the bottom–tracking speed measured by the ADCP. Horizontal sweeps at a range of depths in the bottom boundary layer will be made at intervals of 0.5 m. Square, grided regions of 2 – 5 miles will be surveyed. An operating speed of 3 – 4 knots of the AUV will prove to be suitable for determining turbulence characteristics over a range of time scales. The shear probes and the Pitot tube allow measurement of all three components of fluctuating velocity so that the degree of anisotropy in the small–scale turbulence in the bottom boundary layer environment can be examined. These measurements will also be used to estimate Reynolds stress distribution in the bottom boundary layer. Using the data from the shear probes and the vehicle speed (relative to the local water) reading from the EM current meter, dissipation rates can be determined. From

the dissipation rate profiles, the bottom stress can be estimated in a manner described by Dewey and Crawford[2]. Temperature and vertical velocity measurements will be utilized to estimate the vertical heat flux using the direct method described by Fleury and Lueck[4]. Issues associated with the measurable range of the eddies and the limitations of the current sensors will be determined during the initial phase; the shear probes can certainly measure eddies in the dissipation range, however, it appears that measurement of eddies of the order of 1–2m size are possible. Initial measurements will be made with the aim of establishing the reliability of the developed measurement system. For this purpose, tests will be carried out in a relatively calm region to establish the noise floor for the velocity measurements. Simultaneous measurements using the shear probes and the accelerometers should give indications of any problems associated with vehicle noise. Such checks as well as the comparison between the velocity profile obtained with the EM current meter and that obtained using the ADCP should give significant indication of the reliability of the system. Completely independent checks with other system, as has been suggested, appear to be beyond the scope of the present budget and will be proposed separately. A consistency check, indicating the presence of small–scale turbulence, is provided by the expected $k^{-5/3}$ spatial decay rate of the energy spectrum in the dissipation range; such a decay rate has been observed by other investigators [for example, see 5].

<u>Surface wave measurement</u>. Surface wave data will be obtained using wave gages over the area of study. The wave measurements will be made simultaneously with the turbulence measurement in order to determine the coherence between the measured velocity in the bottom boundary layer and the sea state.

Laboratory Experiment

Sediment transport is a small scale phenomena and is best studied in the laboratory. Once the physical conditions prevailing at a seabed have been elucidated, they can be reproduced in flumes and wave tanks more easily than in the field, allowing proper spatial resolution through use of sufficient number of points. The AUV will allow flow measurements to within 1m of the seabed. Surface shear stress and sediment transport rates would then be needed to be estimated from existing models [2, 5, 6]. However, these have not been completely tested in view of the lack of adequate field data. Available data [7] suggest that in including the influence of wave motion, Grant and Madsen's model [6], for example, gives estimates of the induced shear stress which are larger by one and half to three times those obtained from conventional methods. Thus, in order to accurately measure microtopography and sediment transport, it is necessary to conduct suitable experiments, the results of which are parameterized and related to the measured quantities in the field. In the proposed work, the experimental set up consists of a jet discharging into a wave tank. The tank is 150cm. long, 90cm. wide and 20cm. deep; a longer tank is also available for use if this appears necessary. Waves are generated by an oscillating paddle at one end of the tank. The bottom of the tank is covered with 2cm. deep layer of sand. The jet comprises a brass pipe of diameter 0.35 cm. For all experiments, the discharge Reynolds number based on the pipe diameter is greater than 1000. Parameters of the wave field generated by the wavemaker are $1<kd<2$, where d is the water depth and k is the wavenumber, thus the wave field of the lab model can be regarded as intermediate waves (waves which feel the bottom). As the Reynolds number of the experiments are sufficiently large it is possible to extrapolate the results to the ocean data. The flow field of the lab experiment comprises an interaction of turbulent and mean velocity fields of the jet and wave fields. Experiments will be conducted in three parts a) by locating the jet near the top of the fluid column; b) by locating the jet near the bottom of a fluid column above a solid boundary; c) by locating the jet above a mobile bed comprised of a layer sand. This will allow us to simulate various conditions which may be required to be reproduced in the laboratory. Extensive flow visualization will be undertaken with both reflected light and LIF (light–induced–fluorescence). The velocity field will be determined using both particle tracking (PIV) and hot–film anemometry to resolve both mean velocities and shear stress ($\overline{uw}$). A conductivity probe will be used to measure the scalar field emanating from the jet discharge marked with a passive scalar (salt). Comparison of the measurements of the velocity fields, of the scalar fields and of the jet spreading rates

will discriminate the effects of wave–turbulence–mean flow interactions. Recent studies [8,9] demonstrate that transport rates are augmented by wave stresses. Preliminary results are in accord. Attempts will be made to quantify erosion of the initially flat sand bed by the jet/wave fields. Comparison with the results of the wave field switched on and off will provide data on which to develop parameterizations and transport rates and relate to the measured field data. The work will result in a better understanding of the physics of the near sea–bed environment.

Numerical modeling and computations

Currently available models [2, 6], developed in the seventies, to relate flow measurements to surface–shear stress at the sea–bed and sediment transport treat wave motion and turbulence as being uncorrelated. These models have not been adequately tested through lack of field data on turbulence in the bottom boundary layer[10]. However, in view of the recent advances in experimental techniques and flow visualization methods, our understanding of turbulent boundary layers has improved significantly. In particular, the role of coherent structures in the inner region of a turbulent boundary layer are now known to dominantly govern production and distribution of Reynolds stress and the associated surface–shear stress[11]. These structures significantly respond to oscillatory flow[12] of the type that would be induced by the pressure gradient associated with wave motion. Thus, neglect of the interaction between wave motion and turbulence is expected to result in inaccuracies in prediction of surface–shear stress and sediment transport in significant sea states. It is proposed here to seek improvements in the existing models by taking account of the interaction between wave motion and coherent eddies in the inner region of the turbulent boundary layer. A Navier–Stokes solution to the interaction between coherent structures in the boundary layer and the seabed surface under the influence of oscillatory pressure gradient induced by wave motion will be considered to develop models for eddy viscosity. The physical conditions as measured in the field will be used to consider the interaction and the results will be used to relate the field and laboratory measurements to the surface shear stress. The influence of suspended–load induced stratification on surface shear stress was considered by Glenn and Grant[6]. Such stratification has a significant impact on the local flow field. The model will be tested using the field data. Improvements in the model will be considered, taking account of suspended particle dynamics, as appropriate.

WORK COMPLETED

Significant effort was devoted in the first year (1996) in addressing self noise issues on the turbulence measurement platform and in developing a new pressure probe for measuring fluctuating streamwise component of velocity. In the second year, we have focussed attention on (i) testing the pressure probe by using it to make measurement in grid–generated turbulence in the wind–tunnel, (ii) carrying out turbulence measurement missions in the Gulf Stream at a depth of 150m and in a local outfall in the form of a jet, (iii) in preparing a collaborative Gulf Stream mission with the University of Southampton, to be carried out in December 1997, involving the OEX and their AUV, the Autosub and (iv) implementing self noise measures and considering an optimized platform in the light of the development of smaller AUVs. Task (iii) has resulted in development of a self–contained turbulence package which can easily be fitted on any AUV (see fig 3). Addressing (iv), we have designed a vehicle tail section (see fig 4) optimized for turbulence measurement.

A quieter flooded motor which is being implemented as part of task (iii) also turns out to be an efficient motor and may become standard on AUVs developed at FAU.

Ken Holappa, the PhD student working on the project has completed his dissertation in record time and is due to defend it on November 5, 1997.

RESULTS

A. Shear Probes

Currently we have the ability to produce consistent quality shear probes of the Crawford design. With the goal of being able to measure lower turbulence levels, a new transimpedence amplifier was built based on

the design obtained from Dr. Rolf Lueck. The change to surface mount components reduced the board size from 4” x 5” to 1.5” x 2”. Better op–amps are used in the differentiation stage of the pre–amp. circuit. These improvements should result in a much lower electrical noise floor.

B. Pressure Probe

The most recent design of the pressure probe (figure 1) has eliminated electrical interference and resonance problems experienced with earlier designs. Excellent results comparing the frequency response of the

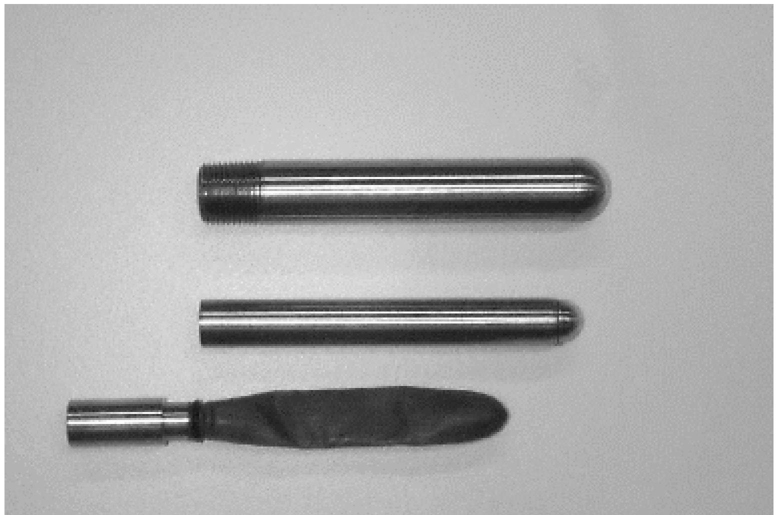

Figure 1. Pressure probe body ant parts.

pressure probe to that of a hot wire probe in a grid generated turbulent field in a wind tunnel were made (Figure 2). It is expected that these results together with turbulent water jet results should be available by Feb. 1998 and a paper submitted for publication by March 1998 on the technology and capabilities of the probe.

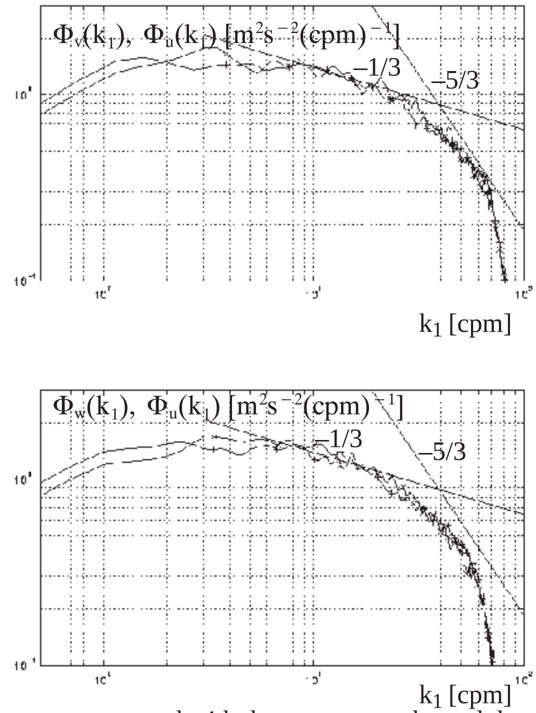

Figure 2. Comparison of velocity spectra measured with the pressure probe and that measured with hot–wire anemometer.

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C. Measurement Missions

The developed platform (figure 3) was successfully used on 2/29/96 to measure turbulence in the Boca Inlet region off the east coast of Florida, the data obtained being of excellent quality. Figure 4 shows the

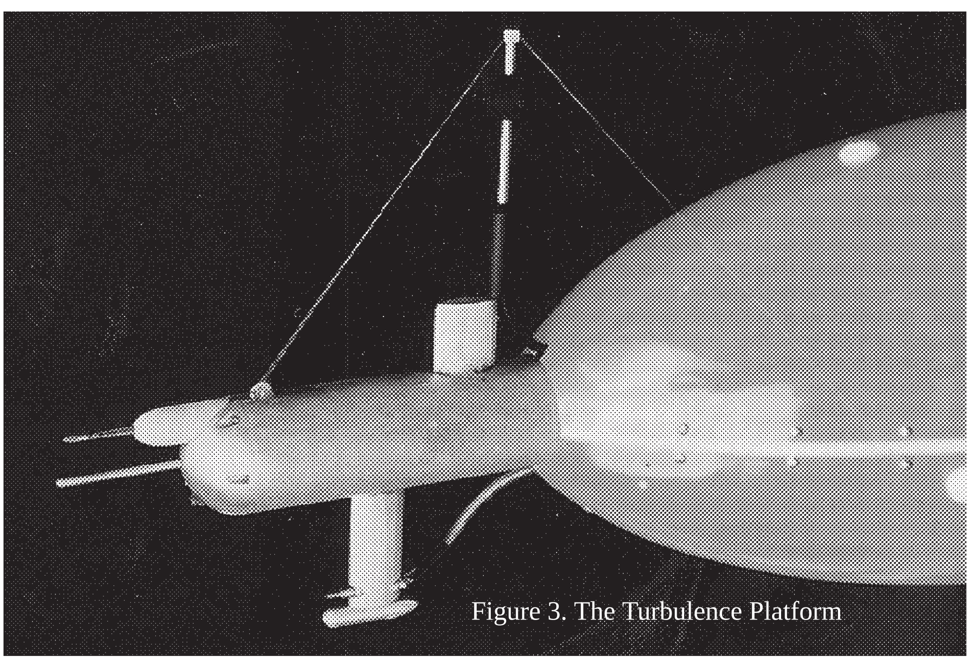

Figure 3. The Turbulence Platform

spectra of the signal measured by the two shear probes. As is evident, the two spectra agree well with each other and with the Nasmyth spectrum. Dissipation rates as low as $O(10^{-8}$ W/kg) were measured.

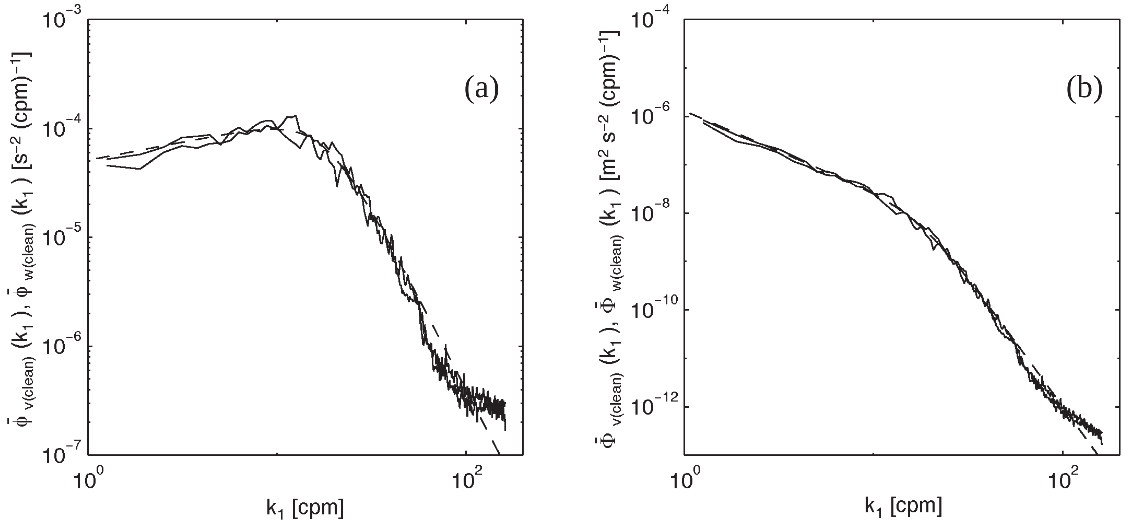

Figure 3. Averaged (a) shear, (b) velocity spectra. Average of the spectra ϕ_v, ϕ_w and associated velocity spectra and Φ_v, Φ_w, over a range of samples, are plotted. – – – : Nasmyth curve for the corresponding average dissipation rate $\bar{\epsilon} = 1.6 \times 10^{-8}$ W/kg.

Gulf Stream and Outfall missions. On 7/16/97, an hour long mission was run with the OEX in 135m deep water in Gulf Stream waters. A large volume of data on ADCP and turbulence measurement has been collected and is being analyzed. A sample segment of data are shown in figure 5. The associated spectra for the y–shear probe together with the y–accelerometer spectra are shown in figure 5. The shear spectra compares well with the Nasmyth spectrum corresponding to dissipation rate of $\epsilon = 5 \text{ X } 10^{-8}$ W/kg. Earlier on the same day, measurements were made in an outfall near Boca Inlet. Again, significant data has been gathered and are being analyzed.

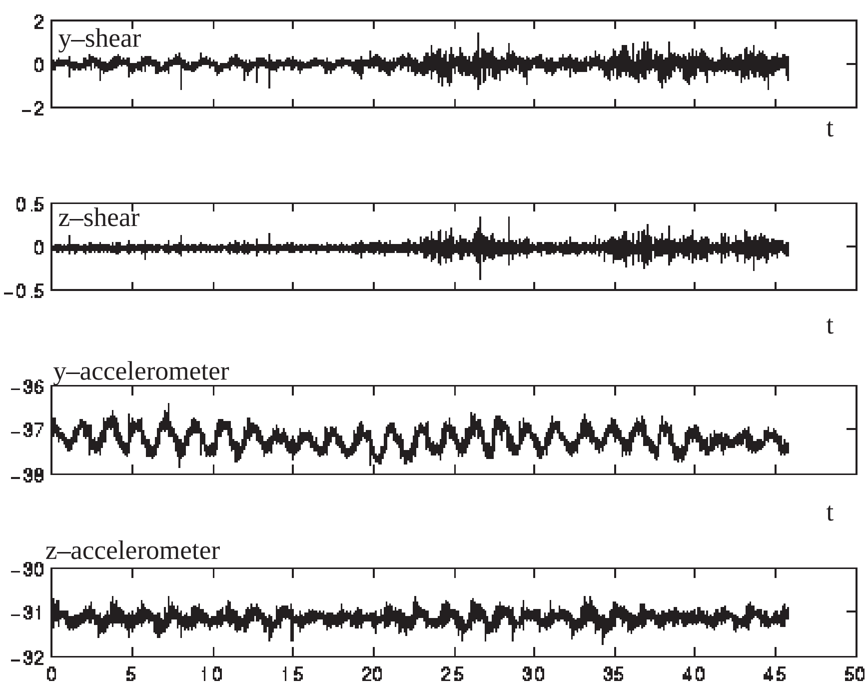

Figure 5. A Segment of Shear Probe and Accelerometer signals measured in the Gulf Stream on 7/16/97.

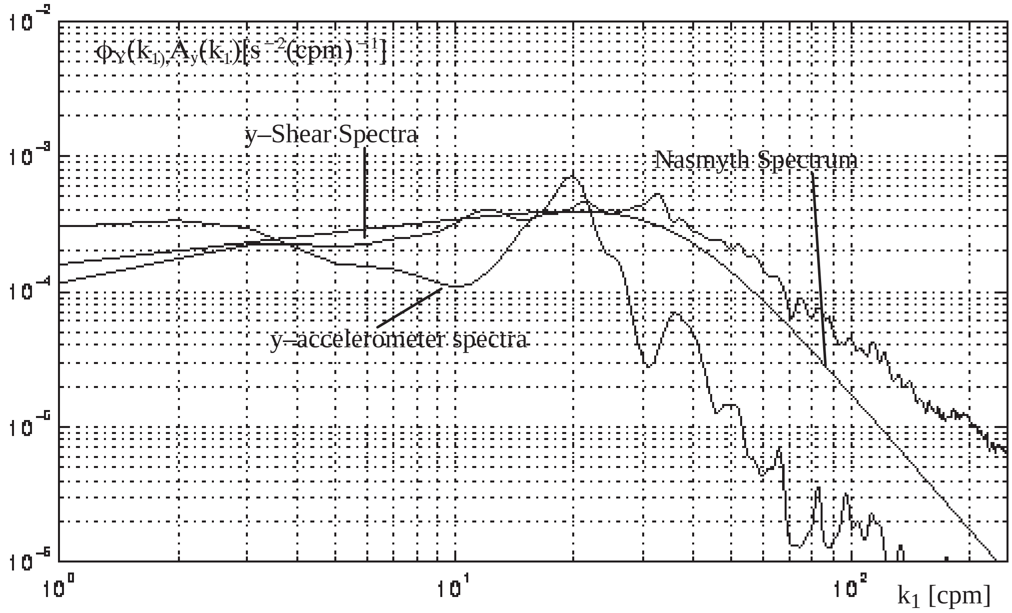

Figure 6. Y–Shear spectra for Gulf Stream mission of 7/16/97.

We are currently gearing up for the collaborative missions using University of Southampton's AUV, the Autosub in December 1997. We have planned a turbulence mission in the Gulf Stream at a depth of 400m. The new smaller turbulence package with vibration isolation mounts is nearly complete and will be used for the scheduled missions.

D. AUV Implementation.

A smaller package for turbulence measurement has been built which can be mounted on any AUV. The size of the package shown in figure 7 has been reduced significantly from the original configuration on the OEX (figure 3). The package is self contained and can be completely mounted external to an AUV. This will reduce the preparation for operations considerably. The smaller package has been mounted with a specially highly damped mounting system which will attenuate vibrations. Research is on going into low vibration thruster systems which will lower vibrations on future AUV designs.

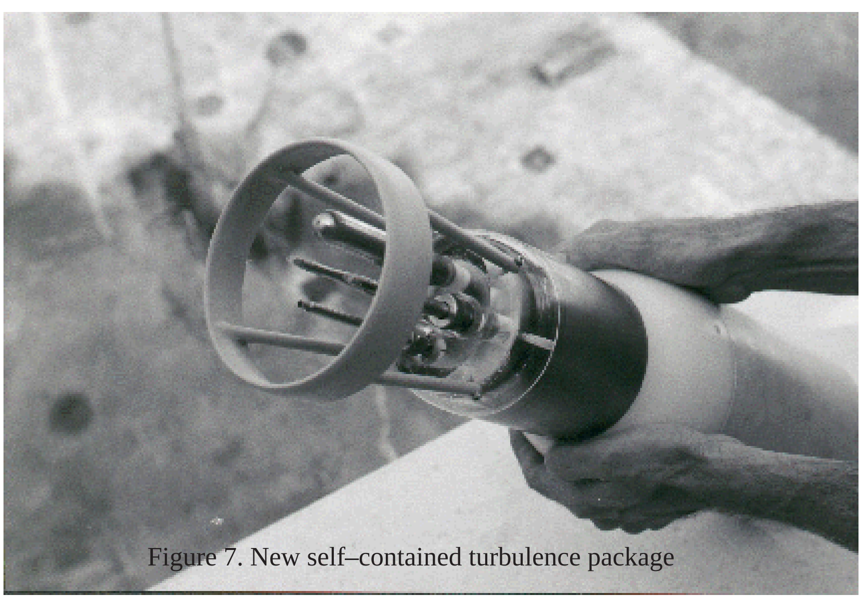

Figure 7. New self–contained turbulence package

E. OEX Tail Section

The tail section of the OEX is currently being redesigned by Dr. Smith's research group. We are working with them to create a very quiet system for turbulence measurement. The design, has been tested on a small AUV (figure 8), and will implement a flooded motor with no seals or gears.

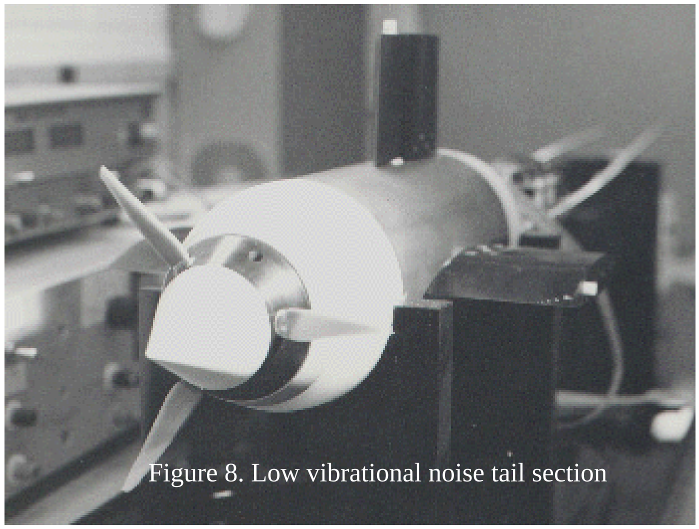
Figure 8. Low vibrational noise tail section

IMPACT/APPLICATIONS

With the development of reliable AUV platforms, four–dimensional maps of the turbulence in the water column can be determined. Turbulence has a significant impact on mixing, sediment transport and biogenic activities in the water column and such maps will help the development and validation of suitable models for characterizing these important processes. The work on sensor development will have a significant impact on the current limitations on wavenumber resolutions of the shear probes. The work on reducing transmitted structural vibrations will help to enhance signal to noise ratios and allow turbulence measurement in relatively less energetic regions using self–propelled mobile platforms.

TRANSITIONS

Progress on current work was discussed with Ed Levine of NUWC during his visit here. He is developing new methods for flow measurement.

RELATED PROJECTS

The work is carried out in conjunction with other ONR–322OM/AOSN projects funded at Florida Atlantic University.

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